

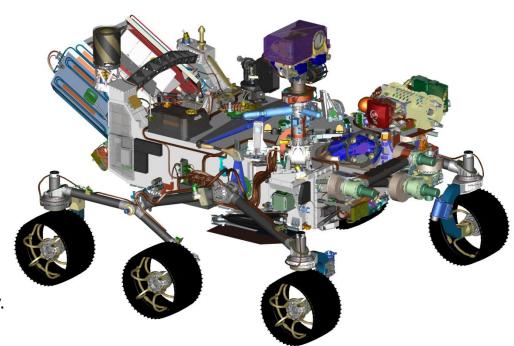
### 2018 Spacecraft Thermal Control Workshop

# Thermal Operability Improvements for the Mars 2020 Rover Surface Mission

Matthew Redmond Jason Kempenaar C.J. Lee Eddie Farias Kaustabh Singh Keith Novak

03/20/2018

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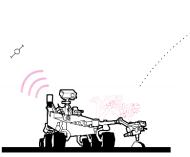


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# **Operability Overview**



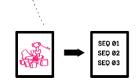
- Significant mission performance gap between what MSL delivered and what M2020 Requires
  - Strong focus on improving operability of M2020



# reduce ground in the loop cycles

#### PRINCIPLE 01

Automate select rover behaviors to allow the rover to make it's own decisions.



#### make plans easy to build

#### PRINCIPLE 05:

Ensure activities that are regularly conducted with the vehicle are easy for operations team to implement.



M2020 Guiding
Principles for
improving
operability



#### remove restricted sols

#### PRINCIPLE 02:

Eliminate restricted sols through a shorter tactical timeline.



#### be fast, be flexible

#### PRINCIPLE 03:

Perform functions (flight and ground) more quickly.

### Comparison of MSL and M2020 Performance

MSL

M2020





1.5

DISTANCE COVERED:

10.6 km

2 scooped
6 drilled samples

MARS YEARS:

15 km

SAMPLES TO COLLECT:

20 drilled samples

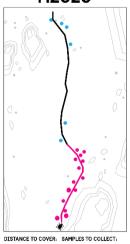
#### **MSL**



DISTANCE COVERED: SAMPLES COLLECTED:

10.6 km 6 drills

#### M2020



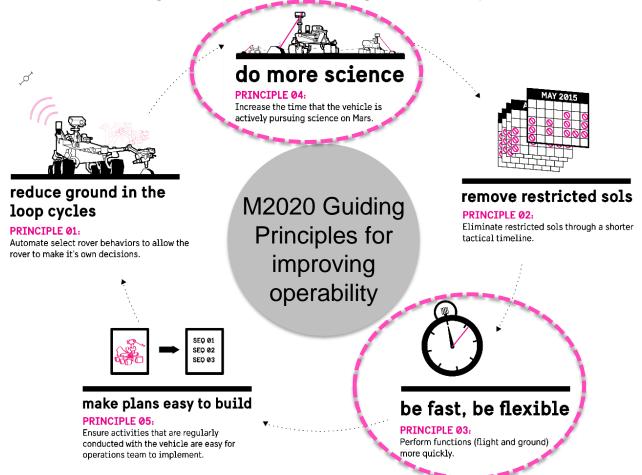
15 km

\* Images from Jennifer Trosper

# **Operability Overview**



- Significant mission performance gap between what MSL delivered and what M2020 Requires
  - Strong focus on improving operability of M2020



#### Comparison of MSL and M2020 **Performance**

MSL

M2020





1.5

10.6 km

2 scooped 6 drilled samples MARS YEARS: 1.5

DISTANCE TO COVER 15 km

20 drilled samples

#### **MSL**



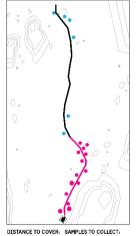
SAMPLES COLLECTED:

6 drills

DISTANCE COVERED:

10.6 km

# M2020



15 km

\* Images from Jennifer Trosper

# Summary of Operability Improvements

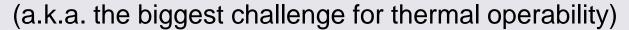


	MSL	Mars 2020				
Mobility Actuator PRTs	1 PRT per mobility actuator; only half (5/10) of the mobility actuator temperatures can be read at once.	2 PRTs per mobility actuator; all 10 mobility actuators can be read at the same time.				
Robotic Arm (RA) PRTs	Each RA actuator had 2 PRTs on the input side only.	Each RA actuator has 4 PRTs – 2 input and 2 output side PRTs.				
Actuator Thermal Modeling	Account for ball bearing conduction with vacuum assumption, but neglect gear-to-gear conduction [1].	Instrumented thermal testing has given us the confidence to account for both ball bearing and gear-to-gear conductance accounting for CO <sub>2</sub> enhancement [2,3].				
Warm Up Algorithms	Algorithms based on season (Ls) and time of day (LTST).	Algorithms use real time PRT data to inform warm ups and operations.				
Landing Site Selection	Landing site selection was provided some information pertaining to thermal operability.	Landing site selection has been provided significant input from the thermal and operations teams.				

#### **Main Focus of This Presentation**

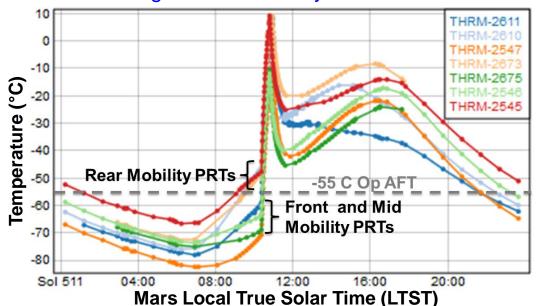
- 1. Novak, K., Liu, Y., Lee, C.-J., and Hendricks, S., "Mars Science Laboratory Rover Actuator Thermal Design," *40<sup>th</sup> International Conference on Environmental Systems*, Barcelona, Spain, July 11-15, 2010.
- 2. Redmond, M., Novak, K., Mireles, V., "Static Ball Bearing Thermal Conductance in Air and Vacuum: Review and Correlation," *AIAA Journal of Thermophysics and Heat Transfer*, Vol. 31, No. 4, 2017, pp. 841-846.
- 3. Redmond, M., Kempenaar, J., and Novak, K., "Mars 2020 Mobility Actuator Thermal Testing and Model Correlation," *47<sup>th</sup> International Conference on Environmental Systems*, Charleston, SC, July 16-20, 2017.

#### Heater Tables On MSL





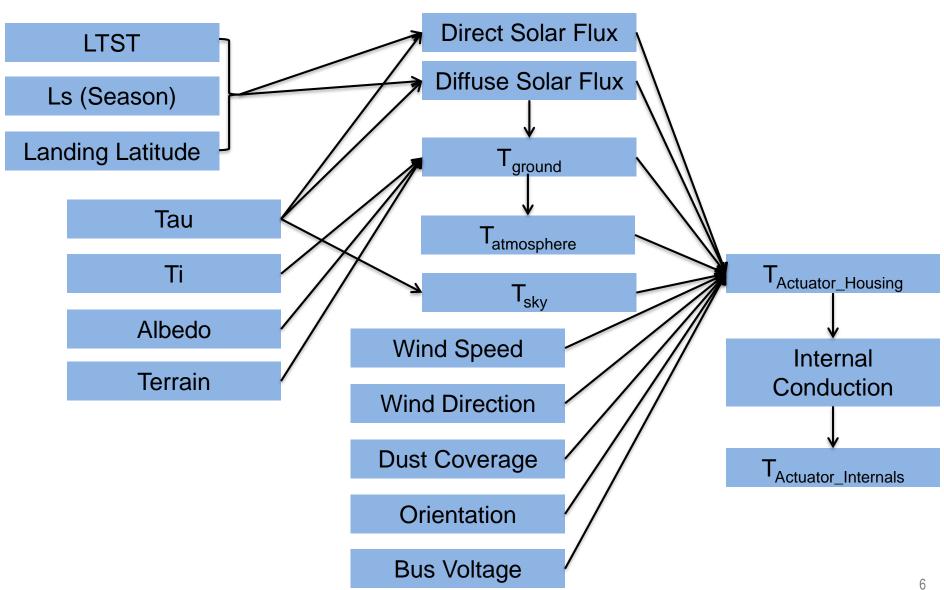
- MSL used heater tables to prescribe warm up times, temperatures, and expected energy consumption.
  - These tables were a function of hardware location, season, time of day, and bus voltage.
    - Generating tables took a significant amount of time.
    - Seasonal resolution was coarse.
  - These tables were cold biased for conservatism.
    - Heater tables on MSL often overestimate warm up time and energy by ~ 2x.
    - The effect is accentuated by RTG warming in some locations.
    - Significant variability between mechanisms in the same heater zone is common.



One of the biggest challenges with heater table prescription is all of the uncertainties involved!

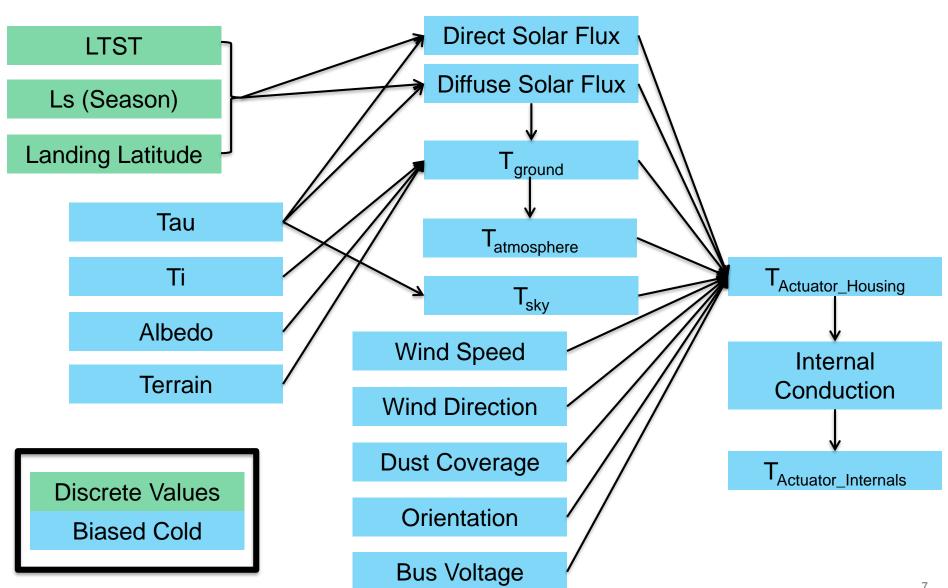
# Warm Up Variables





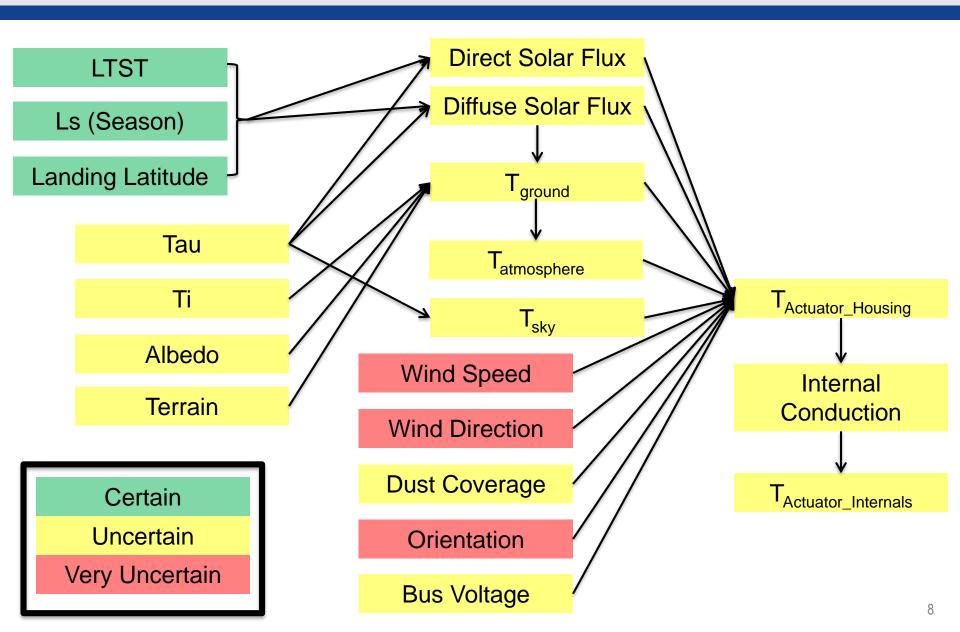
#### Heater Tables on MSL





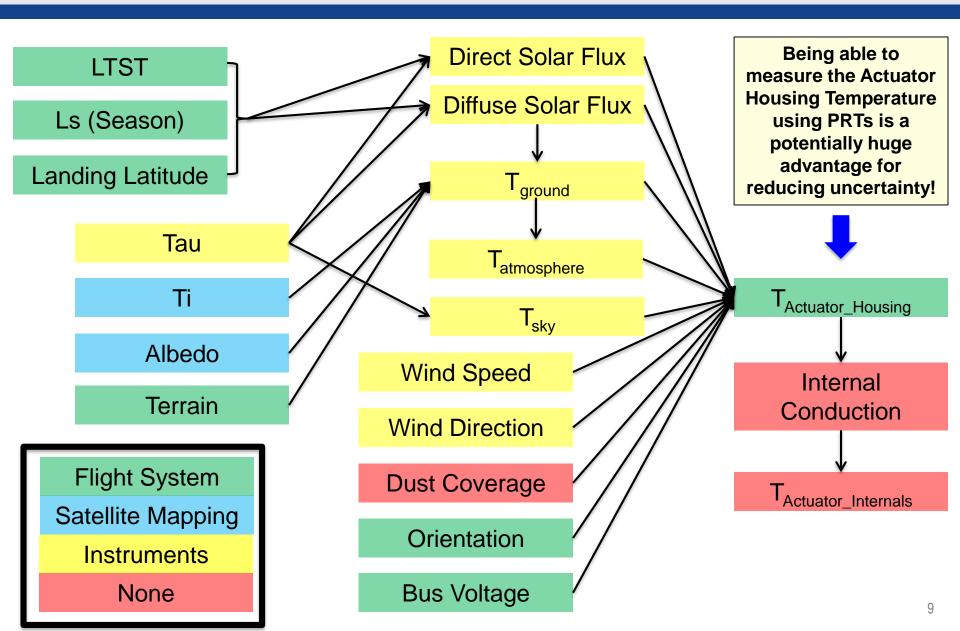
# Uncertainty of Variables





### MSL / Mars 2020 Measurement Capability





# Vocabulary



- Keep Out Window: Window of time when a mechanism cannot be used due to un-heated hardware that is not warm enough (ex: flex cables or cable harness)
- No Heat Window: Window of time when a mechanism does not need heating since it has warmed above its AFT due to environmental heating.
- Warm Up Heating: Active heating of a mechanism prior to use.
- Maintenance Heating: Active heating of a mechanism to ensure that it remains above its AFT once it has already been warmed up.
- Target Temperature: Warm up temperature that must be reached for a zone to be ready to use.
- Target Time: Minimum amount of time needed to warm up a zone to be ready to use.
- High Setpoint: Upper setpoint for maintenance heating
- Low Setpoint: Lower setpoint for maintenance heating

### MSL vs Proposed Mars 2020 Approach

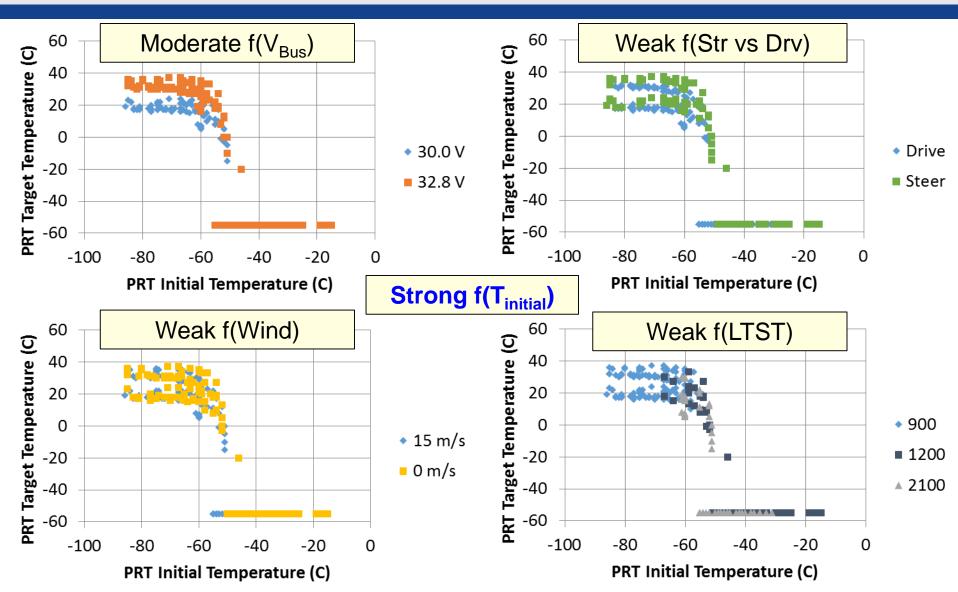


	MSL Approach	Proposed Approach		
Keep Out Windows for Unheated Hardware	Defined by Ls and LTST	Same as MSL		
No Heat Windows for Heated Hardware	Defined by Ls and LTST	Real Time Ops: Based on PRT initial temperature Ops Planning: Based on anticipated PRT reading		
Warm Up Heating	Defined by Ls and LTST	Real Time Ops: Based on PRT initial temperature Ops Planning: Based on anticipated PRT reading		
Maintenance Heating	Defined by Ls and LTST	Same as MSL		

- The proposed Mars 2020 approach was initially evaluated using the 36 mobility model runs with various conditions:
  - 0900, 1200, and 2100 LTST warm up start time (3 variables)
  - Bin 3, 4, and 5 Environments (3 variables)
  - 30.0, and 32.8 V Bus Voltage (2 variables)
  - 0 and 15 m/s wind (2 variables)
- Since the mobility model has 10 actuators, this produced 360 data points.

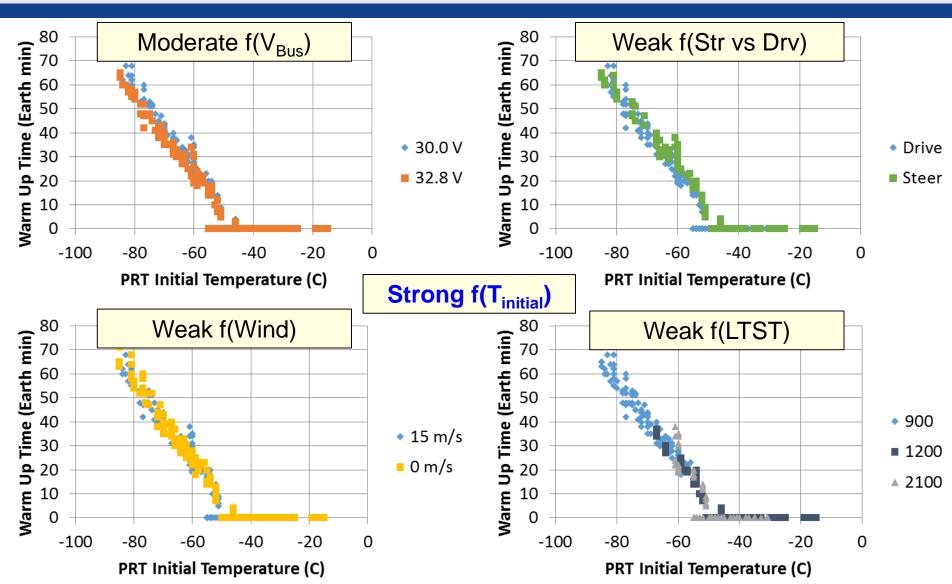
### PRT Target Temperature (360 Data Points)





### Warm Up Time (360 Data Points)

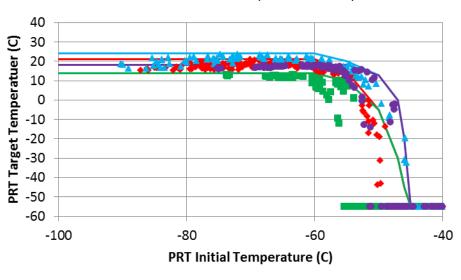


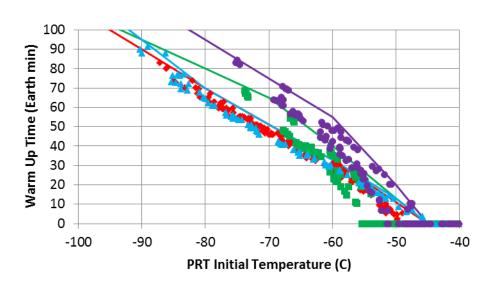


# Proposed Mobility Warm Up Algorithm



- Target Temperature and Target Time assume a nominal 30.0 V Bus Voltage.
  - For V<sub>Bus</sub> > 30.0 V, then the target temperature will be reached early and the zone will have to hold that temperature until the target time is met (time margin).
  - For  $V_{Bus}$  < 30.0 V, then the target temperature will be reached late (temp margin).
- Warm Up Tables were created using the following assumptions:
  - Warm Ups for every hour from 0800 to 2400 LTST.
  - 30.0 V Bus Voltage
  - Bin 3, 4, and 5 Environments (3 variables)
  - 0 and 15 m/s wind (2 variables)





-TABLE Drive, Before 1500 LTST ——TABLE Drive, After 1500 LTST
-TABLE Steer, Before 1500 LTST ——TABLE Steer, After 1500 LTST

Drive, Before 1500 LTST

Steer, Before 1500 LTST

Drive, After 1500 LTST

Steer, After 1500 LTST

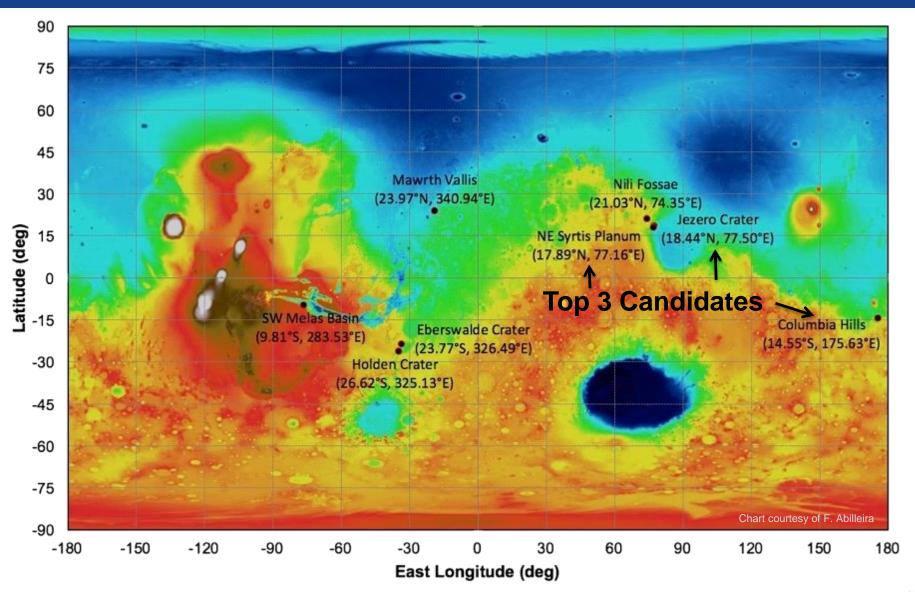
# Landing Site Selection Process



- MSL did not consider the effect that landing site selection could have on surface productivity, since it was initially planned that all mechanisms would be able to operate cold.
  - Gale Crater was a benign thermal environment.
  - Operability could have been much worse at a severe environment like Holden Crater.
- For Mars 2020, the thermal and operations teams have been intentional about communicating the effects that landing site selection could have on surface productivity.
  - Landing site workshop (LSW) thermal analysis were produced, and input into mission productivity analyses for each of the top landing sites.
- Results shown in the following slides were generated for:
  - Landing Site Workshop 3 (February 2017)
  - Landing Site Workshop 4 (Tentative for Summer 2018, TBC)

# Top Landing Site Candidates

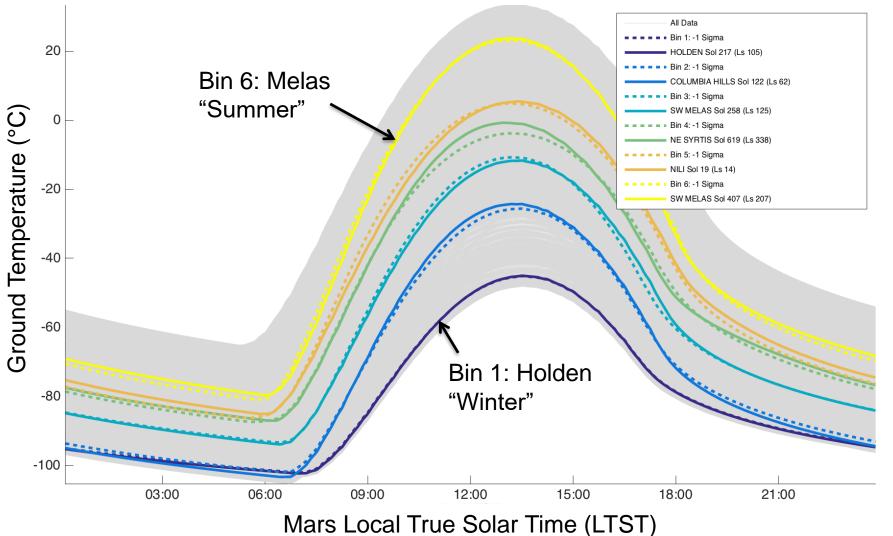




#### LSW: Environmental Bins



 Environments were binned into 6 bins which can be used to approximate any sol at any of top 8 landing sites:

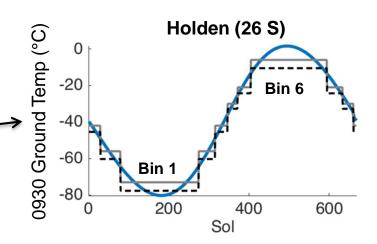


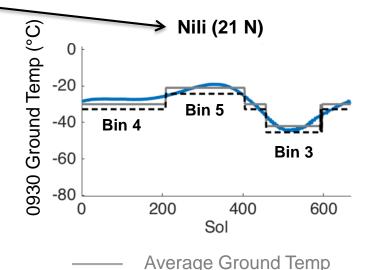
# LSW: Top 8 Landing Sites



- Each landing site can be represented by a certain percentage of each bin.
  - Some northern landing sites only use bins 3-5.
- Bins are biased slightly cold to ensure conservatism in performance modeling.
- Southern Landing Sites:
  - More extreme seasons
  - 2 Winters and 1 summer in prime mission
- Northern Landing Sites:
  - Less extreme seasons
  - 2 Summers and 1 winter in prime mission

	Coldes	→ Warmest				
Bin:	1	2	3	4	5	6
1 Eberswalde (24 S)	25%	16%	12%	8%	12%	29%
2 Columbia Hills (15 S)	0%	33%	15%	10%	16%	25%
3 Holden (26 S)	30%	14%	10%	8%	11%	27%
4 Jezero (19 N)	0%	0%	29%	63%	8%	0%
5 Mawrth (24 N)	0%	13%	18%	42%	27%	0%
6 NE Syrtis (18 N)	0%	0%	23%	61%	16%	0%
7 Nili (21 N)	0%	0%	24%	52%	24%	0%
8 SW Melas (10 S)	0%	25%	19%	12%	21%	22%





-1 Sigma Ground Temp

### Nominal Assumptions for LSW Analysis

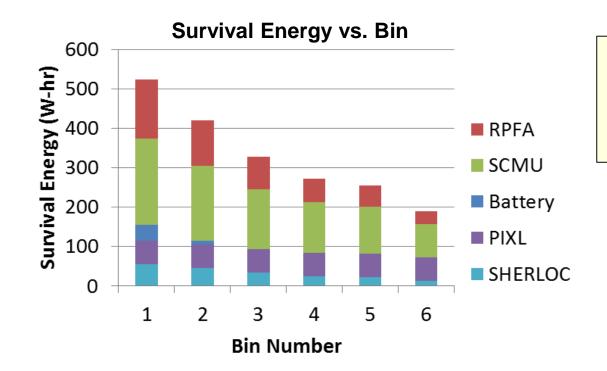


- 8 m/s wind
  - Average wind per Viking Data
- 30 V Bus Voltage
  - Near average of 28 V to 32.8 V range
- 1804 W RTG Power
  - Average of WCC and WCH
- 20% Dust Coverage on Horizontal Surfaces
  - Average value based on MER solar array data
- 5% Dust Coverage on Vertical Surfaces
  - Average of WCC and WCH assumptions
- Science Power Profile on RAMP
  - Assumption is that Rover is doing Science

# Survival Energy



- Rover Pyro Firing Assembly (RPFA) is only used for the first 30 Sols.
- Battery Survival Energy is a strong function of wind speed.
  - Expected to be minimal but could be significant with sustained winds in a cold environment.
- Majority of Survival Energy will be used on Instruments (SCMU, PIXL, and SHERLOC).
  - PIXL survival energy is constant due to seasonally variable setpoints.
- gDRT and Helicopter Electronics not included in analysis (not significant).

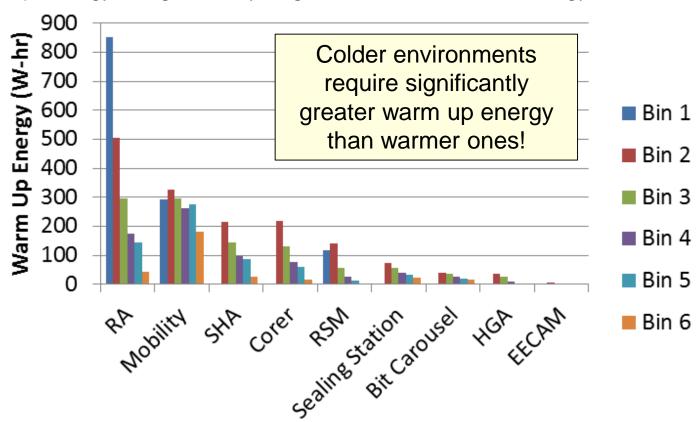


Colder environments require significantly more survival energy than warmer ones!

# Warm Up and Maintenance Energy



- Warm Up is for a 0930 LTST Operational Start Time (where possible).
  - Mobility warm up window depends strongly on Op Window for Unheated hardware, making the warm up energy relatively constant.
  - RSM warm up in Bin 1 environment would need to be delayed due to heater sizing.
- Warm Up Energy is significantly larger than Maintenance Energy.



# Op Windows for 5 Largest Heater Zones

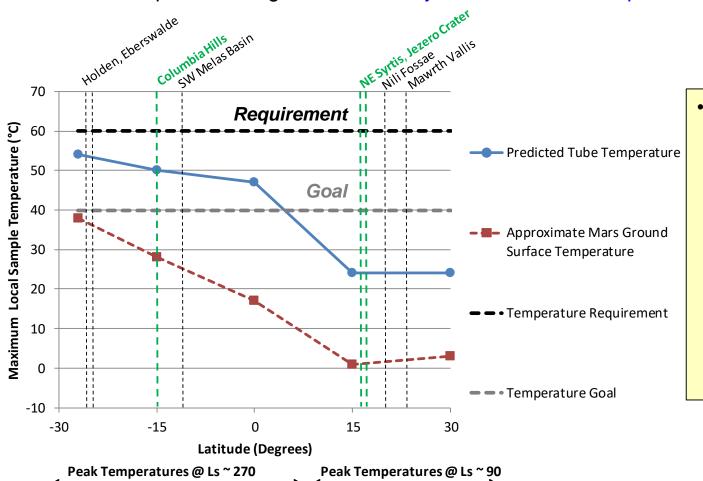


		 	1	1	1	T	T	1.2	F.=	T	1
	Op Windows	10	11	12	13	14	15	16	17	18	19
.⊑	RSM										
	RA										
	Mobility										
	Corer										
	SHA										
Bin 2	RSM										
<b>B</b>	RA										
	Mobility										
	Corer										
	SHA										
Bin	RSM										
B	RA										
	Mobility										
	Corer										
4	SHA										
Bin 4	RSM										
В	RA										
	Mobility										
	Corer										
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Bin	RSM										
В	RA										
	Mobility										
	Corer										
9	SHA										
	RSM										
Bi	RA										
	Mobility										

# Sample Temperature vs. Latitude



- Sample Predicts for the Current Baseline Design:
  - Sample < 60 °C requirement across the entire latitude range.</li>
  - Sample < 40 °C goal across many latitudes and 2 of top 3 landing sites.</li>



- Results are for stacked worst case scenario:
  - 100% Dust (α only)
    - > 10 °C effect
  - TI = 220 Jm<sup>-2</sup>K<sup>-1</sup>s<sup>-1/2</sup>
    - ~ 4 °C effect
  - Albedo of 0.3
    - ~ 5 °C effect
  - No tube-ground contact
    - ~ 5 °C effect
  - Free convection only

#### Conclusions



- Mars 2020 has benefited from the strong foundation created by MSL.
- Mars 2020 has taken lessons learned from MSL to make the new rover more autonomous, easier to operate, and even more scientifically productive.
  - The most significant planned change from a thermal perspective is how heater tables are generated and used.
  - Operational efficiency is expected to be significantly improved by using real time PRT temperature measurements.
- The landing site selection process has also benefitted from improved communication regarding the effects that site selection could have on productivity and science return due to varying climates at each landing site.

### Acknowledgements



We would like to thank Steve Kuhn, Rob Lange, Jessica Samuels, and Jennifer Trosper for their support in a number of discussions related to operability, flight software, and systems engineering for the Mars 2020 rover. Without their inputs, this work would not have been possible.

We also would like to thank the SHERLOC, PIXL, and SuperCAM instrument thermal teams for providing the survival heating estimates used in this package.

#### References



- Novak, K., Liu, Y., Lee, C.-J., and Hendricks, S., "Mars Science Laboratory Rover Actuator Thermal Design," 40<sup>th</sup> International Conference on Environmental Systems, Barcelona, Spain, July 11-15, 2010.
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